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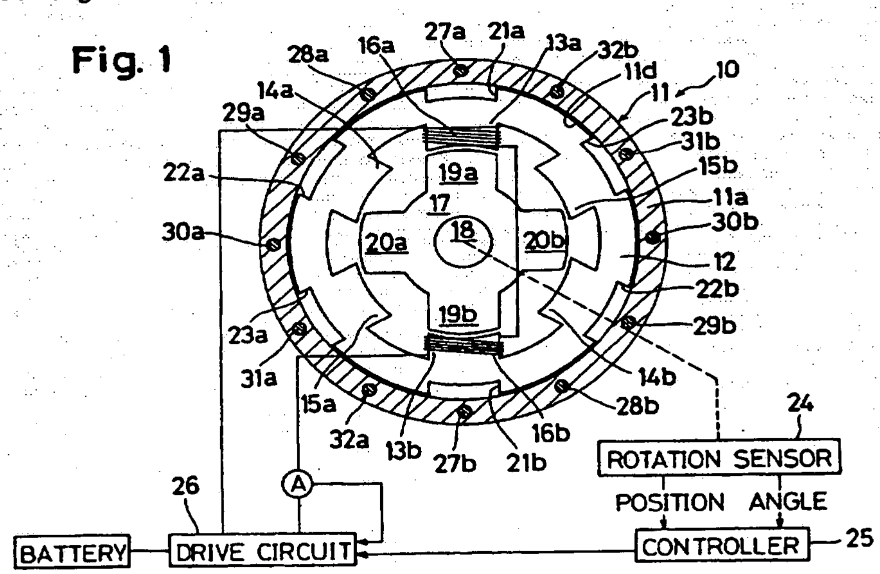
(54) **Suppressing vibration in a switched reluctance motor**

(57) A switched reluctance motor includes a housing 11 having an inner bore extending in an axial direction and a stator 12 fixed in the inner bore of the housing and having a plurality of pairs of opposing stator pole portions which project inwardly in a radial direction and which extend in the axial direction, vibration being suppressed by slots 21, 23 formed on an outer circumferential surface of the stator and extends helically over an arc of predetermined angle and over the length of the stator, and a plurality of stiffening rods 27-32 each of which axially penetrates a part of the housing radially aligned with the stator pole portions. Cooling fluid may additionally pass through the slots.

Fig. 1



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At least one drawing originally filed was informal and the print reproduced here is taken from a later filed formal copy.

Fig. 1

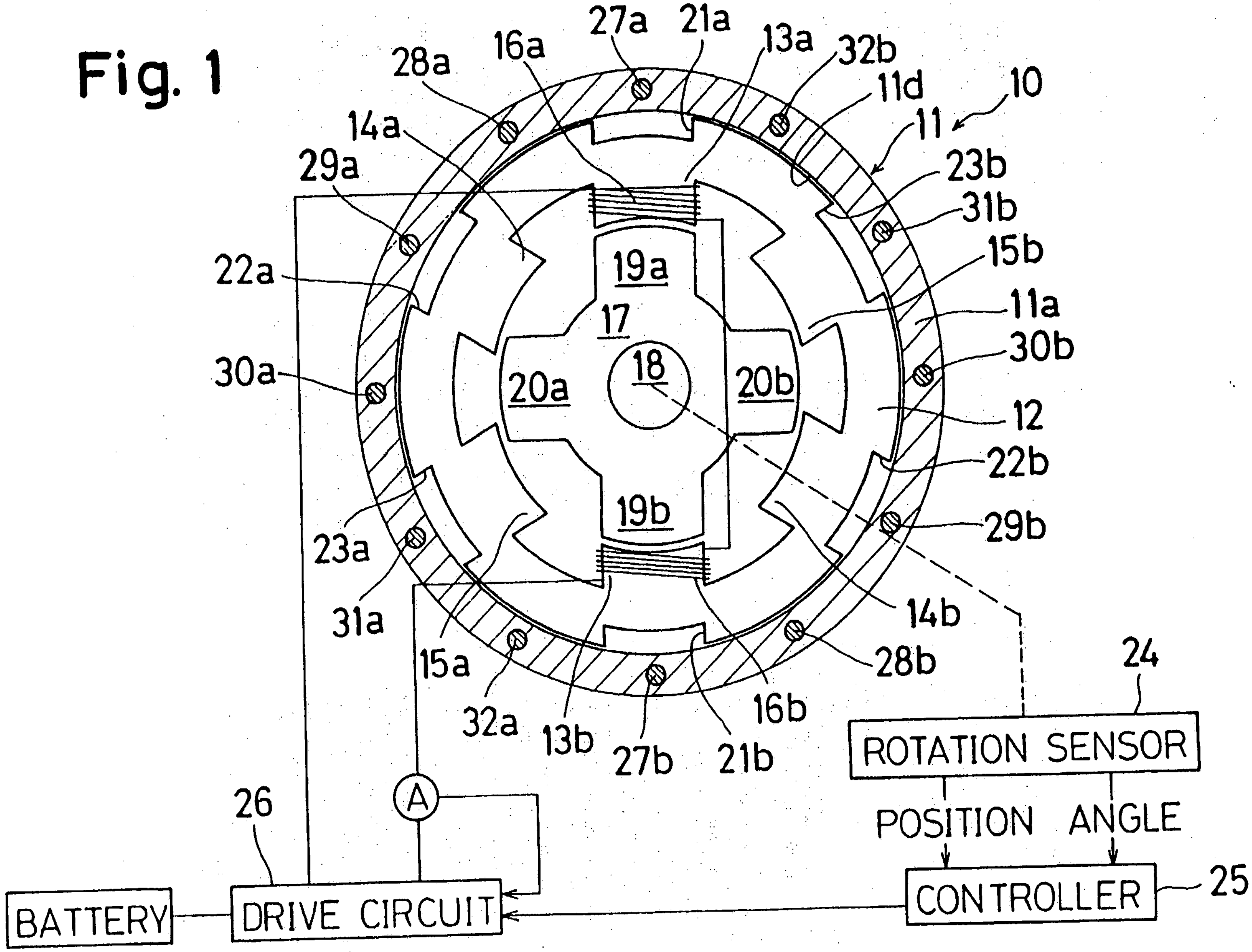

10
11
11d
32b
13a
21a
27a
16a
28a
14a
29a
22a
30a
23a
31a
15a
32a
13b
27b
21b
16b
28b
14b
29b
22b
12
30b
11a
15b
31b
23b
17
18
19a
19b
20a
20b
A
ROTATION SENSOR
24
POSITION
ANGLE
CONTROLLER
25
DRIVE CIRCUIT
26
BATTERY

Fig. 2

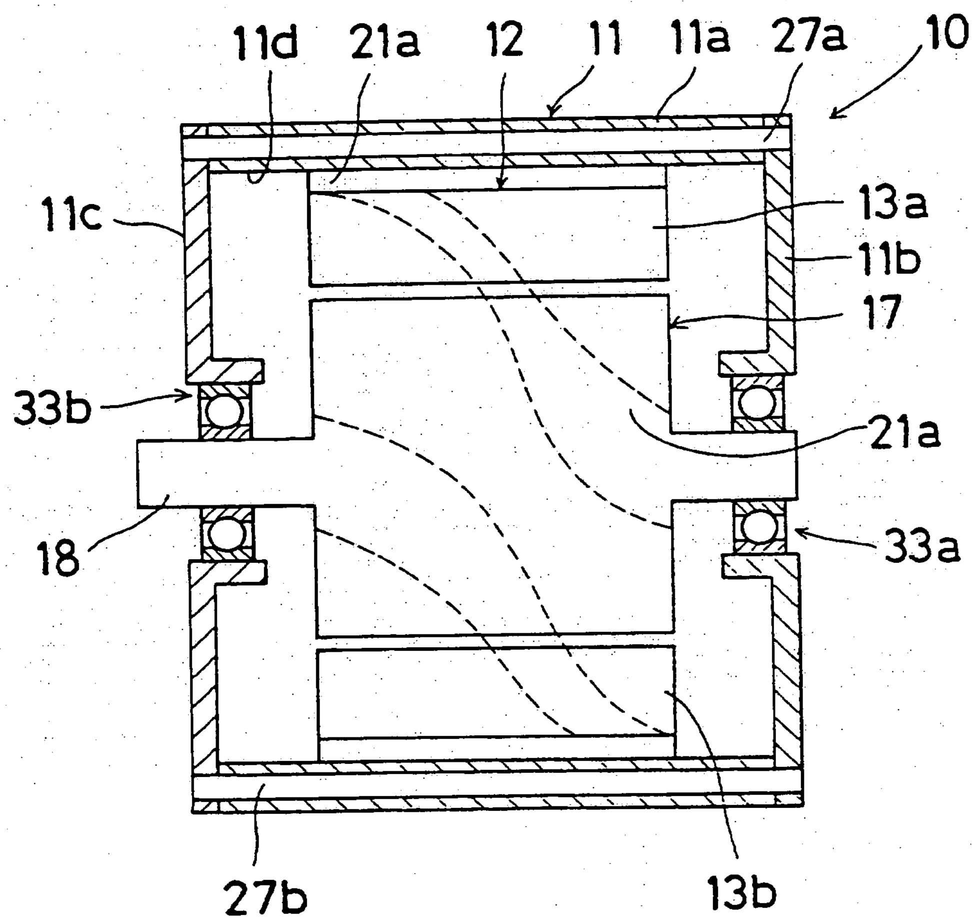
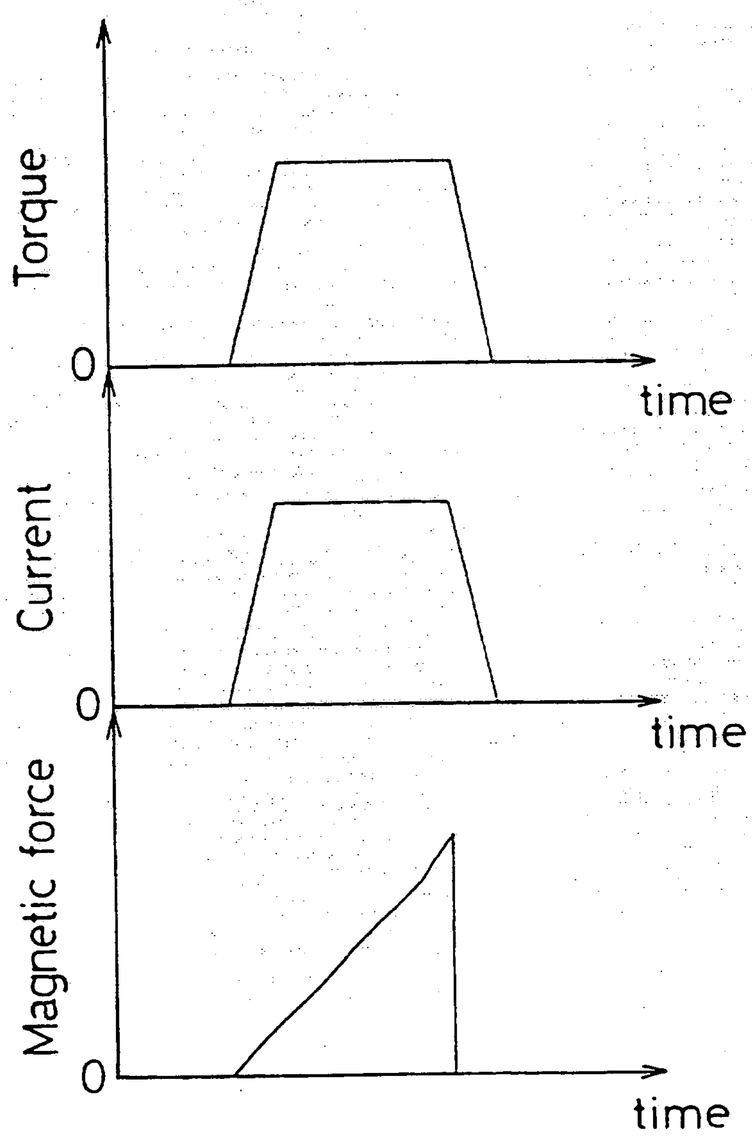


Fig. 3



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TITLE:

Switched reluctance motor

BACKGROUND OF THE INVENTION

1. Field of the Invention:

The present invention relates to a switched reluctance motor.

2. Description of the prior art:

A conventional switched reluctance motor is disclosed in, for example, GB 2231214A. This switched reluctance motor includes a housing, a stator fixed in an inner bore of the housing and formed by laminating of electromagnetic steel plates and a rotor disposed in the stator and formed by laminating of electromagnetic steel plates. The rotor is fixed to an output shaft which is rotatably supported on the housing through bearings and thereby is rotatably disposed in the stator. The rotor has a plurality of pairs of rotor pole portions which project outwardly in the radial direction and which extend in the axial direction. The stator has a plurality of pairs of opposing stator pole portions which project inwardly in the radial direction and which extend in the axial direction. As the rotor rotates, each of the rotor pole portions moves into and out of alignment with each of the stator pole portions but a certain clearance is always maintained beteen the stator pole portions and the rotor pole portions. On each of the stator pole portions, a coil is wound. The coils which are wound on each of the pairs of opposing stator pole portions are connected in series with each other and thereby a magnetic flux is generated between each pair of stator pole portions when current is supplied to the coils. A magnetic attractive force occurs between the rotor pole portions and the stator pole portions as they approach one another. This magnetic attractive force is controlled by controlling supply current with switching elements in response to the

rotational position of the rotor. In this way motoring torque is produced.

The current supplied to the coils wound on one pair or several pairs of stator pole portions is switched on and off as a pulse. In general, the current is switched on when a pair of rotor pole portions approaches alignment with a pair of stator pole portions, and the current is switched off just before the pair of rotor pole portions is aligned with the pair of stator pole portions. Thereby, the magnetic attractive force increases while the current is supplied, and disappears in a moment when the current is switched off. On the one hand motoring torque is obtained by this magnetic attracting force. On the other hand one or more pairs of stator pole portions are attracted radially to the rotor pole portions by this magnetic attracting force, and thereby the stator and the housing are strained.

When the magnetic attractive force disappears, the radially inward strain on the stator ceases and the part of the stator being pulled inward suddenly moves outward. Therefore the housing is pressed outward in the radial direction by the stator. An impulsive strain variation is therefore generated periodically in the housing in response to the rotation of the rotor, causing vibration of the housing and objectionable acoustic noise.

It is, therefore an object of the present invention to provide an improved switched reluctance motor which overcomes the above drawback.

It is another object of the present invention to provide an improved switched reluctance motor which can reduce the objectionable acoustic noise.

<u>THE INVENTION:</u>

The invention provides a switched reluctance motor comprising:

a housing having an inner bore extending in an axial direction;

a stator fixed in the inner bore of the housing and having a plurality of pairs of opposing stator pole portions which project radially inwards and extend in the axial direction, each stator pole portion having a coil wound thereon;

a rotor rotatably disposed in the stator and having a plurality of rotor pole portions which project radially outwards and extend in the axial direction;

at least one slot formed in an outer surface of the stator and extending over an arc of predetermined angle and over substantially the whole axial length of the stator; and

a plurality of stiffening rods each of which axially penetrates a part of the housing and is substantially radially aligned with a stator pole portion.

BRIEF DESCRIPTION OF THE DRAWINGS:

Fig. 1 is a schematic view of an embodiment of a switched reluctance motor in accordance with the present invention;

Fig. 2 is a longitudinal sectional view of an embodiment of a switched reluctance motor in accordance with the present invention; and

Fig. 3 shows graphs of the variation of torque, current and magnetic attractive force on the supply of current to a coil of an embodiment of a switched reluctance motor in accordance with the present invention.

DESCRIPTION WITH REFERENCE TO THE DRAWINGS:

Referring to Fig. 1 and Fig. 2, a switched reluctance motor 10 is provided with a cylindrical housing 11 which is made of aluminium. The housing 11 is composed of a cylindrical portion 11a and side portions 11b,11c which

are fixed to ends of the cylindrical portion 11a. In an inner bore 11d of the housing 11, a cylindrical stator 12 is disposed. The stator 12 is formed by laminating of electromagnetic steel plates and is fixed to the inner bore 11d of the housing 11 at its circumferential portion by heat shrinking.

The stator 12 is provided with three pairs of opposing stator pole portions 13a,13b; 14a,14b; 15a,15b located at regular intervals which project inwardly in the radial direction and which extend in the axial direction. On each pair of stator pole portions, for example, on the pair of stator pole portions 13a,13b coils 16a,16b are wound and are connected in series with each other. Coils (not shown) are wound on each of the pairs of stator pole portions 14a,14b and 15a,15b, and connected in pairs in series. These coils are connected with a drive circuit 26.

In this embodiment, slots 21a,21b,22a,22b,23a,23b are formed on an outer circumferential surface of the stator 12. One end of each slot 21a,21b,22a,22b,23a,23b is located on the outer circumferential surface of a part of the stator 12 on which a stator pole portion 13a,13b,14a, 14b,15a,15b is formed. Each slot extends helically over an arc of 90 degrees and over the length of the stator 12. The width of the slot is equal to the width of the base portion of the stator pole portion in the circumferential direction. Further, the depth of the slot is more than 1 mm.

A plurality of stiffening rods 27a,27b,28a,28b,29a,29b, 30a,30b,31a,31b,32a,32b axially penetrate the cylindrical portion 11a of the housing 11. The rods 27a,b, 29a,b and 31a,b are radially aligned with the stator pole portion and the remaining rods are evenly spaced therebetween. The ends of each stiffening rod are fixed to the side

portions 11b,11c of the housing 11. The stiffening rods are made from a stiff material such as high tensile steel or carbide and are therefore resistant to bending.

A rotor 17 which is formed by laminating of electromagnetic steel plates is fixed on an output shaft 18 which is rotatably supported at its ends in the side portions 11b,11c through bearings 33a,33b. Thereby, the rotor 17 is able to rotate with the output shaft 18 in a body in the stator 12. Furthermore, the rotor 17 is provided with two pairs of opposing rotor pole portions 19a,19b; 20a,20b which are spaced at regular intervals and which project outwardly in the radial direction and extend in the axial direction. As shown in Fig. 1, when the rotor 17 rotates, each of the rotor pole portions moves into and out of alignment with each of the stator pole portions 13a,13b; 14a,14b; 15a,15b while maintaining a certain clearance therebetween.

A well known rotation sensor 24, e.g. such as an encoder or a resolver is disposed on the end (not shown) of the output shaft 18 in order to detect the rotational position of the rotor 17. The rotation sensor 24 is electrically connected to a controller 25 and therefore a position signal and an angle signal detected by the rotation sensor 24 is transmitted to the controller 25.

The controller 25 is electrically connected to the drive circuit 26 to which the coils wound on each of the stator pole portions 13a,13b; 14a,14b; 15a,15b are connected and transmits an output signal to the drive circuit 26 in response to a position signal and an angle signal of the rotation sensor 24. The drive circuit 26 is composed of an inverter using switching elements, such as transistors or thyristors and supplies current such as a pulse to each of the coils in response to the output signal of the controller 25.

The above-described embodiment of the switched reluctance motor 10 operates as follows:

When the rotation sensor 24 detects that the rotor 17 is in a predetermined position in which one of the two pairs of rotor pole portions 19a,19b; 20a,20b begins to approach alignment with one of three pairs of stator pole portions 13a,13b; 14a,14b; 15a,15b, the controller 25 transmits an output signal to the drive circuit 26 in response to the detected signal of the rotation sensor 24. In response to this output signal the drive circuit 26 supplies current to the coils wound on the pair of stator pole portions which the rotor pole portions are approaching. Thereby, the stator pole portions on which these coils are wound are magnetized and a magnetic flux is generated between the magnetized stator pole portions. A magnetic attractive force occurs between the rotor pole portions and the stator pole portions which are approaching them. A component of the magnetic attractive force produces a torque in the rotor 17 which draws the rotor pole portions towards alignment with the stator pole portions.

Once the rotor 17 has been rotated by the torque to a predetermined position in which the pair of rotor pole portions is very nearly aligned with the pair of magnetized stator pole portions, it is detected again by the rotation sensor 24. In this position the rotor 17 is in the final effective position in which the above torque acts on the rotor 17. At this instance the drive circuit 26 stops supplying current to the coils wound on the magnetized stator pole portions, in response to an output signal of the controller 25 made in response to the detected signal of the rotation sensor 24. Thereby, the current supplied to the coils wound on each pair of stator pole portions is switched on and off as a pulse

and a motoring torque is obtained by the action of the above magnetic attractive force. Fig. 3 shows variations of torque, current and magnetic attractive force as current is supplied to the coils wound on a pair of stator pole portions. The above on-off timing of the supply of current is determined in response to the demanded rotation speed or the torque of the switched reluctance motor.

On the other hand, when a pair of magnetized stator pole portions is aligned with a pair of rotor pole portions, the stator pole portions and rotor pole portions are attracted to each other by the above magnetic force. Therefore the stator 12 and the housing 11 are strained. For example, in Fig. 1, the pair of stator pole portions 13a,13b which is aligned with the pair of rotor pole portions 19a,19b is magnetized by the supply of current to the coils 16a,16b and is attracted to the pair of rotor pole portions 19a,19b. As a result, the stator 12 and the housing 11 are strained so that the diameter of the stator 12 and the housing 11 is reduced in the longitudinal direction in Fig.1. When the magnetic force disappears due to the switching off of the current, the inward strain on the stator 12 ceases suddenly and therefore the housing 11 is pressed outwardly in the radial direction by the stator 12. Thereby, an impulsive variation of strain in the housing 11 is generated periodically by the magnetization of each of the pairs of stator pole portions 13a,13b; 14a,14b; 15a,15b.

In this embodiment, the slots 21a,21b,22a,22b,23a,23b are formed on an outer circumferential surface of the stator 12 and are helically extended from the stator pole portions in the axial direction so as to make an arc of 90 degrees over the length of the stator 12. Thereby, the stress applied to the housing 11 by the strain on the stator 12 is distributed by the slots at one end and the

strain in the housing 11 is reduced at this end. On the other hand, at the other ends of the slots, the stress is not distributed and the strain in the housing is not reduced, because the other ends of the slots are not radially aligned with the stator pole portions. Accordingly, in the axial plane, asymmetric strain of the housing 11 is generated. The stiffening rods 27a,27b,28a, 28b,29a,29b,30a,30b,31a,31b,32a,32b act against this asymmetric strain so as to equalize it along the housing. Thereby, the strain in the housing 11 is reduced. As a result, the vibration of the housing 11 is reduced and the objectionable acoustic noise is reduced.

In the abovementioned embodiment, the present invention is applied to a switched reluctance motor which includes a stator having three pairs of stator pole portions and a rotor having two rotor pole portions, However, it is possible to apply the present invention to other types of switched reluctance motors, for example a switched reluctance motor which includes a stator having six pairs of stator pole portions and a rotor having four pairs of rotor pole portions. In this case, twelve slots are formed on the outer circumferential surface of the stator and the slots are similar to those described in the above embodiment, but each slot helically extends in the axial direction so as to make an arc of 45 degrees over the length of the stator. Namely, the angle of the helical slot is a half of the angle between the stator pole portions which are magnetized at the same time.

As mentioned above, according to the present invention, asymmetric strain is generated in the housing in the axial plane by the function of the helical slot and this asymmetric strain is equalized by the stiffening rod. Accordingly, the strain and the vibration of the housing is reduced and thereby it is possible to reduce the objectionable acoustic noise caused by the vibration of

the housing.

Furthermore, according to the present invention, it is possible to effectively cool the housing and the stator which are heated by magnetization, if a heat-exchanger fluid such as air, oil, or water is supplied to the helical slots.

CLAIMS:

1. A switched reluctance motor comprising:
a housing having an inner bore extending in an axial direction;
a stator fixed in the inner bore of the housing and having a plurality of pairs of opposing stator pole portions which project radially inwards and extend in the axial direction, each stator pole portion having a coil wound thereon;
a rotor rotatably disposed in the stator and having a plurality of rotor pole portions which project radially outwards and extend in the axial direction;
at least one slot formed in an outer surface of the stator and extending over an arc of predetermined angle and over substantially the whole axial length of the stator; and
a plurality of stiffening rods each of which axially penetrates a part of the housing and is substantially radially aligned with a stator pole portion.

2. A switched reluctance motor as recited in claim 1, wherein the predetermined angle is half of the angle between stator pole portions which are magnetized at the same time.

3. A switched reluctance motor as recited in claim 1 or claim 2 wherein one end of the slot is substantially radially aligned with a stator pole portion.

4. A switched reluctance motor substantially as described herein with reference to the drawings.